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ORIGINAL ARTICLE

Comparison of Cardiovascular Parameters and Internal Training Load of Different 1-h Training Sessions in Non-elite CrossFit® Athletes

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Abstract

Purpose The fact that CrossFit® is the best-known and rapidly growing concept for high-intensity interval training (HIIT) and high-intensity functional training (HIFT) results in a continuous increase of athletes performing CrossFit®. In the more than 15,000 CrossFit® Affiliates worldwide, the training concept is usually offered in 1-h training sessions containing the CrossFit®-related workout of the day (WOD), as well as a general warm-up, movement demonstrations, and skill training. Here, we report how physiological parameters measured by heart rate (HR) values vary during four different 1-h CrossFit® training sessions of non-elite athletes ($n=27$) in a local affiliated training center and what influencing factors may exist.

Methods The duration of the 1-h training sessions were divided into a warm-up part (WU-part), a skill development part combined with strength exercises (A-part), followed by the WOD part (B-part).

Results Analysis of HR values shows high training intensity ($\geq 91\%$ HR_{max}) not throughout the duration of each training session, only during B-part. The mean HR values in B-part differ significantly compared to the remaining training parts ($P<0.001$) for all four training sessions. Comparison of different CrossFit® experience levels revealed no significant difference in acute physiological demands and training load between beginner and experienced CrossFit® athletes.

Conclusion Our results may suggest that practicing CrossFit® in 1-h training sessions combined anaerobic and aerobic exercise intensities, with the training concept allows beginners and experienced athletes to be trained with the same cardiovascular responses and training intensities.

Keywords CrossFit® performance · Training load · Exercise intensity · Cardiovascular response · High-intensity functional training

Introduction

The new training concept CrossFit® belongs to the most growing and popular types of high-intensity interval training (HIIT) and high-intensity functional training (HIFT) that counts over 15,000 affiliates training centers worldwide (CrossFit). Due to its increasing popularity and the multiple fitness improvements of CrossFit® training [4, 6], recent studies have investigated the physiological and cardiovascular responses [25–27].

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CrossFit® focuses on constantly varied functional movements executed at a high intensity and includes exercises from the main elements of gymnastics (e.g., Pull-Ups, Push-Ups, and Burpees), weightlifting (Power lifts, e.g., Back Squats, Deadlifts, and Olympic lifts, e.g., Snatch, Clean & Jerk) and cardiovascular activities (e.g., running, rowing, and jumping) usually performed as "workout of the day" (WOD) [17]. In affiliated training centers, CrossFit® training is commonly performed in 1-h classes consist of a warm-up part (WU-part), a part of skill development, possibly combined with strength exercises (A-part), followed by a 10–20-min part involving the WOD at a high intensity (B-part) with short or no intervals between exercises and as required, stretching exercises [18]. Greg Glassman's CrossFit® training principle assumes that all three energy systems (the phosphagenic pathway, the glycolytic pathway, and the oxidative pathway) are targeted during training, controlled by duration, intensity, and programmed exercises to improve performance. CrossFit® determines fitness as a result of training and improvements in each of these energy-delivery systems [16]. The combination of aerobic, anaerobic, and resistance training within each training session presents CrossFit® as an extremely effective training method for inducing improvements in cardiovascular fitness and body composition in athletes of all levels of fitness [15, 26, 31], in accordance with the key idea of CrossFit®, which is accessible to everyone by scaling CrossFit® workouts [19]. Scaling means the ability to adjust the intensity of each exercise of the workout to the individual fitness level as shown by Butcher et al. [3]. To better understand the effectiveness of CrossFit® training [4], the previous studies have examined cardiovascular and metabolic responses, as well as ratings of perceived exertion (RPE) of CrossFit® training protocols with varied durations ranging from ultra-short protocols of less than 2 min [28], to shorter protocols of only a few minutes (2–8 min) [13, 27, 35, 37, 38], and to longer protocols (20–30 min) [3, 12, 25, 41]. Tibana et al. examined the differences between shorter and longer CrossFit® sessions, and showed that both protocols achieved heart rate (HR) values over 90% maximal heart rate (HR_{max}) during training, with no significant differences [35]. In addition, differences between different CrossFit® training modalities such as "as many rounds as possible" (AMRAP) vs. "for time" (FT) have been investigated and show no differences in cardiovascular responses [13, 41].

According to the American College of Sports Medicine (ACSM) guidelines, previous studies reported that mean HR values during the CrossFit® workouts can be considered vigorous and close to maximal (~90% HR_{max}) overall [14]. However, only isolated WODs have been investigated as CrossFit® training routines, and no study has investigated a 1-h CrossFit® training session as commonly offered commercially by affiliated CrossFit® training centers [18]. Due to the intensity of the training, the used workload of CrossFit® WODs can be too excessive for some individuals, and a few studies reported increased acute cardiovascular stress [42], increased pro-/anti-inflammatory cytokines [34], injuries [11, 35], and rhabdomyolysis [20]. However, there is a lack of evidence of CrossFit® training as a risk of overtraining. Observational studies [11, 24, 32] suggest a comparable risk of injury to other sports and suggest that practicing CrossFit® in affiliated training centers incorporates more than the typically investigated WOD. To achieve positive physiological adaptations such as performance enhancement without the risk of overtraining and injury, it is essential to adopt an appropriate training load (TL). One of the major challenges in CrossFit® science is the quantification of internal TL, due to the wide variety of exercises used, external TL (e.g., speed, pace, distance, and repetitions) is a poor tool for monitoring. Few previous studies investigated the assessment of internal TL of CrossFit® training, e.g., during 38 weeks of CrossFit® training for an elite female athlete in a case study [36] and validated by session RPE method to quantify internal TL during HIFT [8, 10, 35, 36]. Although the variation of TL in different types of CrossFit® training "AMRAP" vs. "FT" has been recently shown by Toledo et al. [41], however to the best of our knowledge, it is not yet known how the TL varies in non-elite athletes between 1-h CrossFit® training sessions. To date, a few available studies have only examined the effect of separate CrossFit® WODs on physiological responses such as HR values [3, 12, 13, 25, 27, 35] but not the effect of CrossFit® practicing in 1-h training sessions, which maintain the WOD but incorporate even more. Understanding the physiological responses to different structures of CrossFit® training may help athletes to improve their training requirements and thus improve their results [4]. We suggest that a better understanding of how CrossFit® is performed in real training conditions like in 1-h training sessions by athletes of different levels of CrossFit® experience and its effects allows reducing the risk of injury and optimizing athletic performance. For this reason, we intend to examine whether a 1-h CrossFit® training session targets three energy-delivery systems and what cardiovascular responses are induced in each part of the training. We suppose that only in the B-part including the WOD of a 1-h training session, HR values above 90% HR_{max} will be observed, as described by the previous studies, while the other parts of the training session differ significantly in their exercise intensity. Furthermore, the acute effects of a 1-h CrossFit® training session on different levels of experience have not yet been investigated. Butcher et al. revealed that performing CrossFit® in high-intensity continuous (circuit) or HIIT modalities by advanced participants achieved higher mean HR values than the beginner group [3]; however, he did not investigate the HR throughout a 1-h training session. We therefore asked whether there are differences in the cardiovascular response of different levels of experience and whether a 1-h training session format is suitable for achieving multiple physiological and performance adaptations in beginners and experienced athletes by aerobic, anaerobic, and resistance training. We hypothesize that training programming with the CrossFit® concept is suitable for both beginners and experienced athletes to be trained in the same 1-h training session regardless of their levels of experience.

To characterize the cardiovascular response, as measured by HR values, during 1-h CrossFit® training sessions, we observed four training sessions from a local affiliated training center and analyzed the training intensity in different training parts of the training session. Furthermore, we compared the acute physiological demands of beginner and experienced none-elite CrossFit® athletes to determine if different CrossFit® experience levels impact.

Materials and Methods

Participants

In this study, 27 CrossFit® Athletes (male = 18; female = 9) participated, with an average age of 30.9 ± 4.2 years. The Athletes had a CrossFit® experience of 16.1 ± 13.3 months with a training scope per week of 2.9 ± 0.9 h; as in Table 1. All participants attended the 1-h training sessions offered at a local affiliated training center of CrossFit® and signed an informed consent form prior to participation. To investigate real training conditions, participants were not selected according to any other inclusion criteria such as minimum CrossFit® experience. The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Ethics Committee of the University of the Bundeswehr Munich, Germany.

Experimental Approach

To characterize the cardiovascular response in different parts of 1-h CrossFit® training session, four regular training sessions of a local affiliated training center were observed within 1 week. At the beginning of each examination, participants signed the informed consent statement, and the anthropometric data of the participants were collected. HR measurement was performed to determine the cardiovascular response. The participants were fitted with an HR monitor to begin observation of each 1-h CrossFit® training session. On consecutive days, the 1-h CrossFit® training session, subsequently named Training Sessions 1–4, was conducted. Each training session was divided into three parts, the first part includes general warm-up and movement demonstrations (WU-part), followed by a part with lifting and skill training (A-part), and the last part containing the CrossFit®-related WOD (B-part). The programming of each training session is shown in Table 2. Participants performed the provided exercises as indicated or scaled depending on their performance capacity.

Furthermore, to compare the cardiovascular response and the internal TL between different levels of CrossFit® experience, the participants were classified by their previous knowledge of CrossFit® training as beginners with up to 6 months of CrossFit® experience (hereafter referred to as beginner) and as experienced CrossFit® athletes with over 6 months of experience (hereafter referred to as experienced) [3, 6]. Thereby, the ratio between females and males was comparable with 62.5% males and 37.5% females among beginner and 68.42% males and 31.58% females among experienced participants in two groups.

Measures

Heart Rate

Subjects were fitted with an HR monitor (Polar H-10 sensor, Büttelborn, GER) and the HR was measured prior to starting the training session (HRpre), and during the training session. During each CrossFit® training session, HR averages were recorded every 2 s. HR data were stored and subsequently extracted into CVS files using the “Club-community in flow” app (Polar, Büttelborn, GER) and analyzed using Microsoft Excel spreadsheet program and SPSS version 26.0 (IBM, Armonk, NY, USA). The HR values were averaged for each training session in the three parts (WU-, A- and B-part), so that the average HR values of each training part were obtained (HR_{mean} WU, HR_{mean} A, and HR_{mean} B). In addition, the average heart rate was calculated over the entire duration of each training session (HR_{mean}). To compare HR data, HR_{max} was calculated for each participant using the equation $208 - 0.7 \times \text{age}$ [33]. Once the calculated HR_{max} was exceeded by the HR peak observed during the CrossFit® training sessions, the HR peak observed during the CrossFit® training session was used for HR_{max}. To compare the training intensity of the different training sessions, the percentages time of participants spent in the five intensity zones by Edwards (up to 60% HR_{max}; 60%–70% HR_{max}; 70%–80% HR_{max}; 80%–90% HR_{max}; and 90%–100% HR_{max}) during the training sessions were also calculated.

Table 1 Participant characteristics

Parameters	All	Beginner	Experienced	*P* value*
n	27	8	19	
Age (years)	30.9 ± 4.2	31.3 ± 3.7	30.7 ± 4.4	0.776
Height (cm)	179.1 ± 9.1	177.4 ± 9.4	179.8 ± 9.1	0.531
Weight (kg)	79.8 ± 11.9	77.5 ± 13.2	80.7 ± 11.5	0.529
Training scope per week (h)	2.9 ± 0.9	3.0 ± 0.9	2.9 ± 0.9	0.791
CrossFit® experience (months)	16.1 ± 13.3	4.9 ± 1.6	20.9 ± 13.2	0.002

The values are expressed as mean ± standard deviation (SD)

*Difference between groups of different level of CrossFit® experience

Table 2 Training program of Training Sessions 1–4 divided into three parts with respective durations

Training sessions	Training Session 1	Training Session 2	Training Session 3	Training Session 4
Time (min)	61	64	53	56
WU	Row Mobility	Burpees, Sit-Ups, Push-Ups, Air Squats and Lunges Mobility	Row Mobility	Row Mobility
Time (min)	18	28	20	22
A	Deadlift 4–4–4–4–4	Every 90 s for 15 min High Hang Snatch Overhead Squat	Every 90 s for 15 min 3 Power Clean (90% of 1-RM)	Strict Pull-Ups (weighted) 3 × 3–5
Time (min)	21	19	25	16
B	Team Lumberjack (in Teams of 2) 20 Deadlift 400 m Run 20 Kettlebell Swings 400 m Run 20 Overhead Squats 400 m Run 20 Burpees 400 m Run 20 Chest to Bar Pull-Ups 400 m Run 20 Box Jumps 400 m Run 20 Squat Cleans 400 m Run	AMRAP 18 Jumping Lunges 15 Sit-Ups 12 Hand Release Push-Ups 9 Box Jump overs, 60 cm for males, 50 cm for females	3 rounds for Time 21 Kettlebell Swings (Russian), 24 kg for males, 16 kg for females 15 Med Ball Cleans 9 Toes to Bar	"Fight Gone Bad" 3 rounds 1 min Wall Ball Shots, 9 kg for males, 7 kg for females 1 min Sumo Deadlift High Pull, 35 kg for males, 20 kg for females 1 min Box Jumps, 60 cm for males, 50 cm for females 1 min Push Press, 35 kg for males, 20 kg for females 1 min Row for Calories 1 min Rest
Time (min)	22	16	8	18

Each training session was divided into three parts: the first part was a warm-up (WU), followed by a lifting and skill part (A) and the last part including the workout of the day (B)

AMRAP as many rounds as possible, *RM* repetition maximum

Training Load

To compare the internal TL of the four 1-h CrossFit® training sessions, the HR-based method proposed by Edwards was used. This method integrates the total volume of the training session with the total intensity of the exercise session relative to five intensity zones. For each training session, the TL per hour was calculated by multiplying the accumulated duration in each HR zone with a multiplier allocated to each zone (up to 60% $HR_{max} = 1$, 60%–70% $HR_{max} = 2$, 70%–80% $HR_{max} = 3$, 80%–90% $HR_{max} = 4$, and 90%–100% $HR_{max} = 5$) and then summated [9].

Statistical Analysis

All data are presented as mean ± standard deviation (SD), and descriptive statistics were performed on HR data and on participant characteristics; see Table 1. Data were tested for normality distribution by the Shapiro–Wilk test ($P < 0.05$) and Q–Q plots and for homogeneity of the variance by Levene's test. Using boxplots, outliners were identified. To assess the effects of the different training sessions on HR values measured during each training part and on the TL, a one-way ANOVA was conducted with Bonferroni post hoc analysis to determine significant differences between the HR and TL values. For each training session, a repeated-measures ANOVA with a Greenhouse–Geisser correction was conducted to assess differences in HR in percentage of HR_{max} between the different training parts. The sphericity was confirmed through the Mauchly test and the effect size by eta squared. The Greenhouse–Geisser adjustment was used to correct for violations of sphericity. Furthermore, a two-way ANOVA was performed to analyze the effect of levels of CrossFit® experience and the four different training sessions on HR values and the TL. The level of statistical significance was $P < 0.05$. Analyses were performed using the software package SPSS version 26.0 (IBM, Armonk, NY, USA).

Results

Analysis of Training Sessions 1–4

To characterize the cardiovascular response of four different 1-h CrossFit® training sessions by measuring the HR values and analyzing the training intensity in different training parts of the training session, the resulting HR values and the calculated TL of each training session are shown in Table 3.

We conducted a one-way ANOVA to assess the effects of different training sessions on HR measured during each training part and on the TL. Each training session was divided into the WU-part, A-part, and B-part; in these parts, the mean HR for each part was calculated. There were no outliers, according to inspection with a boxplot. Data were normally distributed for each group (Shapiro–Wilk test, $P > 0.05$ and Q–Q plots) and there was homogeneity of variance (Levene's test, $P > 0.05$). For HR data, the one-way ANOVA showed significant differences between training sessions for mean HR, for mean HRpre, for mean HR in WU-part and A-part in bpm, and in percentage of HR_{max}; as in Table 3. There was no statistically significant difference in mean HR in B-part for the different training sessions in bpm [F (3, 31) = 109.88, $P = 0.336$] and in percentage of HR_{max} [F (3, 31) = 26.62, $P = 0.310$]. The average TL per hour was highest in Training Session 2 (173.9 ± 19.2), and lower in Training Session 1 [− 22.4, 95%CI (− 53.1, 8.3)], Training Session 3 [− 28.6, 95%CI (− 62.3, 5.1)], and Training Session 4 [− 28.6, 95%CI (− 60.15, 2.9)]. No statistically significant difference was found for the TL between the different training sessions [F (3, 31) = 2.86, $P = 0.053$].

For Training Session 1, mean HR in percentage of HR_{max} was the highest in the B-part (85.25 ± 4.06), and lower in the A-part (61.76 ± 7.31), WU-part (54.68 ± 5.10), and PRE of the Training Session 1 (44.26 ± 5.52). To assess differences in HR values between the different training parts, repeated-measures ANOVA with a Greenhouse–Geisser correction determined that mean HR in percentage of HR_{max} showed a statistically significant difference between training parts of Session 1 [F (1.98, 17.79) = 173.70, $P < 0.001$,

Table 3 Comparison of heart rate (HR) values and training load (TL) between the four 1-h CrossFit® training sessions

Variables	Training Session 1 $n = 10$	Training Session 2 $n = 9$	Training Session 3 $n = 7$	Training Session 4 $n = 9$	P value
HR_{max}					
(beats/min)	187 ± 2.0	188 ± 6.0	188 ± 4.0	188 ± 3.9	0.967
HR_{pre}					
(beats/min)	83 ± 10.6	88 ± 10.3	85 ± 11.3	72 ± 6.6	0.011
(% HR_{max})	44.26 ± 5.52	46.75 ± 4.17	45.09 ± 5.85	38.44 ± 3.34	0.006
HR_{mean}					
(beats/min)	128 ± 8.9	139 ± 9.7	128 ± 14.4	126 ± 8.8	0.047
(% HR_{max})	68.23 ± 4.55	73.93 ± 3.20	68.14 ± 7.43	67.09 ± 4.26	0.025
HR_{peak}					
(beats/min)	182 ± 7.2	182 ± 11.8	178 ± 12.0	183 ± 6.3	0.729
(% HR_{max})	97.25 ± 3.84	96.67 ± 3.81	94.38 ± 6.18	97.30 ± 2.65	0.486
HR_{mean} WU					
(beats/min)	103 ± 9.9	128 ± 9.3	112 ± 13.1	103 ± 9.0	< 0.001
(% HR_{max})	54.68 ± 5.10	68.26 ± 3.63	59.29 ± 6.46	55.07 ± 4.29	< 0.001
HR_{mean} A					
(beats/min)	116 ± 14.2	131 ± 11.0	130 ± 16.5	110 ± 13.9	0.006
(% HR_{max})	61.76 ± 7.31	69.53 ± 3.80	68.96 ± 8.54	58.42 ± 7.18	0.004
HR_{mean} B					
(beats/min)	160 ± 7.6	168 ± 11.7	165 ± 12.1	166 ± 7.2	0.336
(% HR_{max})	85.25 ± 4.06	89.10 ± 4.31	87.74 ± 6.50	88.32 ± 3.76	0.310
TL					
(TL/h)	151.5 ± 20.7	173.9 ± 19.2	145.3 ± 37.1	145.3 ± 17.3	0.053

The values are expressed as mean ± standard deviation (SD)

HR heart rate, HR_{pre} heart rate previous training session starts, HR_{max} maximum heart rate, % percentage, HR_{peak} maximum heart rate during training session, *WU* warm up-part, *A* A-part, *B* B-part, *TL* training load, *h* hour partial $\eta^2 = 0.95$]. The Bonferroni-adjusted post hoc analysis revealed significant differences ($P < 0.001$) in mean HR in percentage of HR_{max} between all training parts of Training Session 1; as in Table 4. Mean HR in percentage of HR_{max} was significantly higher in the B-part (85.25 ± 4.06) of Training Session 1 than in the remaining parts, with a mean difference of 31.69 (SE = 2.03), Bonferroni-adjusted $P < 0.001$, partial $\eta^2 = 0.96$; see Fig. 1.

The repeated-measures ANOVA with a Greenhouse–Geisser correction showed a statistically significant difference between training parts of session 2 for mean HR in percentage of HR_{max} [F (2.02, 16.12) = 264.35, $P < 0.001$, partial $\eta^2 = 0.97$]. Although no significant difference was found between mean HR in the WU-part and the A-part, Bonferroni-adjusted post hoc analysis revealed significant differences ($P < 0.001$) in mean HR as a percentage of HR_{max} between each of the other training parts of session 2; as in Table 4. Overall, the mean HR in percentage of HR_{max} was significantly higher in the B-part (89.10 ± 4.31) of Training Session 2 than in the other training parts, with a mean difference of 27.58 (SE = 1.25), Bonferroni-adjusted $P < 0.001$, partial $\eta^2 = 0.98$.

Mean HR in percentage of HR_{max} showed a statistically significant difference between training parts of session 3 [F (1.51, 9.05) = 117.35, $P < 0.001$, partial $\eta^2 = 0.95$], determined by a repeated-measures ANOVA with a Greenhouse–Geisser correction. The Bonferroni-adjusted post hoc analysis revealed significant differences ($P < 0.001$) in mean HR as a percentage of HR_{max} between mean HR in B-part and A-part, between B-part and WU-part, and between B-part and PRE-part. Besides, significant differences ($P < 0.05$) were found between A-part and WU-part, A-part and PRE-part, and WU-part, and PRE-part; as in Table 4. With a mean difference of 29.96 (SE = 1.88), the mean HR in percentage of HR_{max} was significantly higher in the B-part (87.74 ± 2.45) of Training Session 3 than in the other training parts, Bonferroni-adjusted $P < 0.001$, partial $\eta^2 = 0.98$.

Also in Training Session 4, the repeated-measures ANOVA with a Greenhouse–Geisser correction showed a statistically significant difference between training parts for mean HR in percentage of HR_{max} [F (2.13, 14.94) = 237.34, $P < 0.001$, partial $\eta^2 = 0.97$]. The Bonferroni-adjusted post hoc analysis revealed significant differences ($P < 0.001$) in mean HR as a percentage of HR_{max} between all four training parts in session 4, between WU-part and PRE-part by $P < 0.05$; as in Table 4. The mean HR in percentage of HR_{max} was significantly higher in the B-part (88.29 ± 1.42) than in the other training parts of Training Session 4, with a mean difference of 38.12 (SE = 1.71), Bonferroni-adjusted $P < 0.001$, partial $\eta^2 = 0.99$.

Training Intensity

During all training sessions, HR values ≥ 91% of HR_{max} were achieved. Considering the entire duration of the training session, 41 min was required to achieve ≥ 91% of HR_{max} during Training Session 1, 49 min during Training Session 2, 46 min during Training Session 3, and 42 min during Training Session 4. If only considering the B-part, with the WOD, Training Session 3 attained ≥ 91% of HR_{max} the fastest with 63 s, followed by Training Session 2 with 104 s, Training Session 1 with 169 s, and Training Session 4 with 230 s. Likewise, when observing the overall training duration, HR values ≥ 91% of HR_{max} are shown to be the least proportion of training time and occur during B-part, as well. To analyze the training intensity of the different training sessions (supplementary Fig. 1) shows the percentage of time spent by participants in the different HR zones during the training sessions. Athletes spent in average 14.08% ± 8.71% of the training time at intensities ≥ 91% of HR_{max}, followed by 15.00% ± 6.50% of the training time at intensities

Table 4 Pairwise comparisons of the mean heart rate (HR) in percentage of the maximum heart rate (HR_{max}) for the training parts PRE, WU, A and B by Bonferroni-adjusted post hoc analysis

Comparisons	Training Session 1		Training Session 2		Training Session 3		Training Session 4	
	d (%)	95%-CI	d (%)	95%-CI	d (%)	95%-CI	d (%)	95%-CI
HR_{mean} B vs. HR_{mean} A	23.49**	16.22–30.77	19.56**	16.42–22.70	18.78**	13.01–24.55	30.32**	22.56–38.08
HR_{mean} B vs. HR_{mean} WU	30.58**	23.96–37.19	20.84**	15.92–25.75	28.45**	20.97–35.93	33.66**	26.94–40.38
HR_{mean} B vs. HR_{mean} PRE	40.99**	32.78–49.20	42.35**	35.30–49.40	42.65**	30.36–54.94	50.37**	42.93–57.82
HR_{mean} A vs. HR_{mean} WU	7.08**	3.13–11.03	1.28	− 3.31–5.86	9.68*	3.39–15.96	3.34**	− 2.05–8.73
HR_{mean} A vs. HR_{mean} PRE	17.50**	10.86–24.13	22.79**	17.72–27.85	23.87*	11.47–36.27	20.05**	11.03–29.08
HR_{mean} WU vs. HR_{mean} PRE	10.42**	6.83–14.00	21.51**	15.67–27.35	14.19*	6.74–21.64	16.71*	11.93–21.50

HR heart rate, HR_{pre} heart rate previous training session starts, % percentage, HR_{peak} maximum heart rate during training session, *WU* warm up-part, *A* A-part, *B* B-part, *d* difference, *CI* confidence interval

**$P < 0.001$; *$P < 0.05$

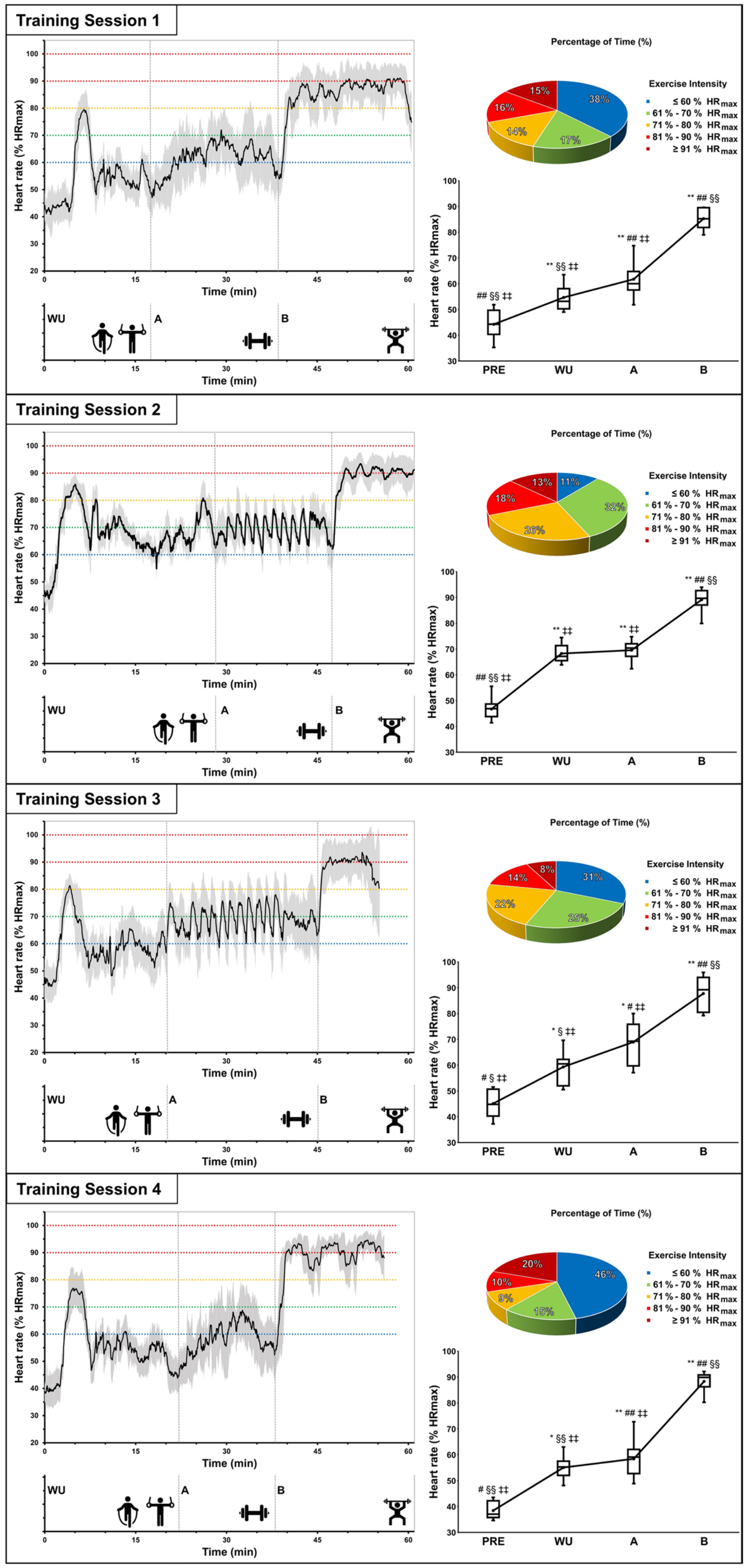

Fig. 1 Relative Heart rate (HR) values of HR_{max} during CrossFit® Training Sessions 1–4 with standard deviation of HR shown as shaded area. The duration of Training Session 1 in minutes is divided into three parts by gray dotted lines: Warm-up part (WU), followed by a lifting and skill part (**A**) and the last part with the workout of the day (**B**). The exercise intensity in the different HR zones is represented by colored dashed lines and shown separately in percentage of time (%) in the HR zones in a circular diagram. Differences in mean HR values between the different training parts: *Significant difference in relation to PRE ($P < 0.05$); **Significant difference in relation to PRE ($P < 0.001$); $^{\#}$Significant difference in relation to WU ($P < 0.05$); $^{\#\#}$Significant difference in relation to WU ($P < 0.001$); §Significant difference in relation to A ($P < 0.05$); §§Significant difference in relation to A ($P < 0.001$); ‡‡Significant difference in relation to B ($P < 0.001$)

81%–90% of HR_{max}, 17.50% ± 8.98% of the training time at intensities 71%–80% of HR_{max}, 22.04% ± 9.97% of the training time at intensities 61%–70% of HR_{max}, and the most of time the athletes spent in ≤ 60% of HR_{max} by 31.39% ± 18.42%.

Comparison of Different Levels of CrossFit® Experience

Furthermore, we asked whether different levels of CrossFit® experience affect the cardiovascular response as measured by HR values during the four 1-h training sessions. To examine the effect of levels of CrossFit® experience and the four different training sessions on HR values and TL, we performed a two-way ANOVA. The level of CrossFit® experience has been divided into beginner with up to 6 months of CrossFit® experience and experienced athletes with over 6 months [6]. There were no outliers, according to inspection with a boxplot. Data were normally distributed for each group (Shapiro–Wilk test, $P > 0.05$ and Q–Q plots) and there was homogeneity of variance (Levene's test, $P > 0.05$). A two-way ANOVA revealed that there was not a statistically significant interaction between the effects of levels of CrossFit® experience and the four 1-h training sessions. Simple main effects analysis shows that level of CrossFit® experience did not have statistically significant effects on any HR value or the TL, *P* values; as in Table 5.

For within-levels of CrossFit® experience comparisons of cardiovascular responses to each training session, significant differences were found for mean HR (in percentage of HR_{max}) in WU-part as well in beginner [F (3, 9) = 7.67, $P < 0.05$] as in experienced athletes [F (3, 21) = 8.65, $P < 0.001$] (Fig. 2).

Table 5 Comparison of heart rate (HR) values and training load (TL) in beginners and experienced CrossFit® athletes

Variables	Beginner ($n = 8$)	Experienced ($n = 19$)	*P* value
HR_{max}			
(beats/min)	189.25 ± 4.76	187.42 ± 3.67	0.261
HRpre			
(beats/min)	79.50 ± 11.46	82.92 ± 11.16	0.570
(%HR_{max})	42.00 ± 5.89	44.20 ± 5.44	0.417
HR_{mean}			
(beats/min)	128.43 ± 12.80	131.25 ± 10.70	0.691
(%HR_{max})	67.84 ± 6.15	70.00 ± 5.12	0.440
HR_{peak}			
(beats/min)	181.56 ± 8.42	181.46 ± 9.20	0.930
(%HR_{max})	95.73 ± 5.23	96.86 ± 3.66	0.523
HR_{mean} WU			
(beats/min)	108.35 ± 15.76[a]	112.42 ± 14.29[a]	0.589
(%HR_{max})	57.25 ± 7.47[a]	59.97 ± 7.30[b]	0.376
HR_{mean} A			
(beats/min)	116.81 ± 17.60	122.61 ± 15.62	0.503
(%HR_{max})	61.78 ± 9.11	65.37 ± 7.59	0.367
HR_{mean} B			
(beats/min)	164.49 ± 10.70	164.44 ± 9.76	0.969
(%HR_{max})	86.92 ± 5.30	87.77 ± 4.50	0.725
TL			
(TL/h)	147.8 ± 28.6	157.1 ± 24.4	0.497

The values are expressed as mean ± standard deviation (SD) and *P* value for variables between the levels of CrossFit® experience

HR heart rate, HR_{pre} heart rate previous training session starts, HR_{max} maximum heart rate, % percentage, HR_{peak} maximum heart rate during training session, *WU* warm up-part, *A* A-part, *B* B-part, *h* hour

[a]Difference between training session ($P < 0.05$)

[b]Difference between training session ($P < 0.001$)

Discussion

The results of this study demonstrate for the first time that practicing CrossFit® in 1-h training sessions, divided into different training parts, showed significantly different cardiovascular responses measured by HR values across the separate parts of the training sessions; however, by comparing athletes with different levels of CrossFit® experience, there were no significant differences of the cardiovascular responses. We therefore suggest that 1-h training sessions offered by affiliated training centers are likely suitable training methods to reach the recommended target exercise intensities for both beginners and experienced CrossFit® athletes.

Characterization of the cardiovascular demand of four 1-h duration of CrossFit® training sessions divided into different parts according to training scope, consisting of a warm-up part (WU-part), a skill development part, possibly combined with strength exercises (A-part), followed by the WOD part at high intensity (B-part) were the main findings of this study. The primary result shows that HR values (expressed as % of HR_{max}) above 90% HR_{max} are achieved in all four 1-h training sessions; however, in particular, these values were only observed in the B-part of the session, containing the WOD and differ significantly with 27.58%–38.12% more of HR values to the other parts. Our findings contrast with other studies by showing how the cardiovascular response varies throughout a 1-h training session. According to previous studies, it was assumed that CrossFit® training mainly performed in HR values above 90% HR_{max} [3, 12, 13, 25, 27, 41]. Furthermore, the comparison of the HR values between the four training sessions shows that the average values differ in the WU-part and the A-part; only in the B-part, no significant differences were found across the training sessions. This is an interesting finding, on one hand, the different HR values in the WU-part and A-part could be explained by the

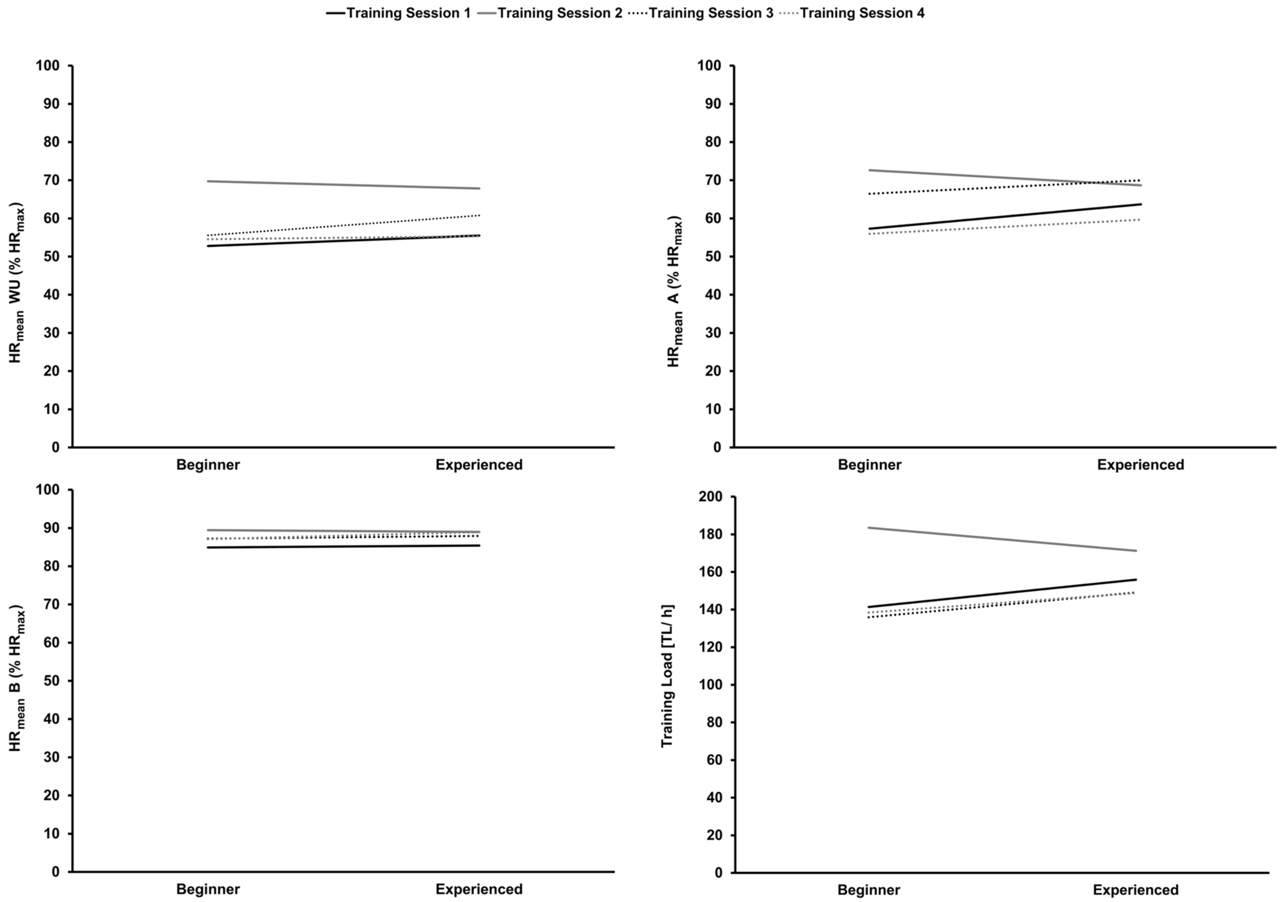

Fig. 2 Difference in Heart rate (HR) values for mean HR in WU-part, A-part, and B-part in % of HR_{max} and Training load (TL) between beginner and experienced CrossFit® athletes

different training programming, on the other hand, different WOD training modalities in the B-part do not lead to significant differences between the training sessions.

To the best of our knowledge, no previous study has examined the cardiovascular responses of a 1-h CrossFit® training session commonly offered at affiliated training centers. To date, several studies have only been able to show that HR values do not differ between different CrossFit® workouts when the WOD was investigated [13, 41]. Therefore, as the WOD is performed in the B-part in our approach, the results are consistent with the findings of previous studies regarding the HR values (expressed as % of HR_{max}) during WODs [12, 27, 35]. Thereby, in our study, different training modalities of the WOD were examined during each B-part. In Training Session 1, the WOD "in Team of 2", in Training Session 2 the training modality "ARAMP", in Training Session 3 the modality "FT" and in Training Session 4 the benchmark WOD "Fight Gone Bad" were performed, despite the different WOD types, the mean HR values did not differ significantly across the modalities. Thus, we suggest that all four different WODs are suitable for achieving HR values above 90% HR_{max}, as showed in some former studies [35, 41].

The present study explains the significant difference in the cardiovascular response of the other parts of the training session (WU- and A-Part) investigated with the fact that, for the first time, a 1-h training session was observed and not just a WOD alone. On average, high HR values above 90% HR_{max} were only reached after three-quarters of the training time and not after a few seconds, as Tibana et al. previously postulated [35]. Therefore, observing the entire duration of the training sessions contributes significantly to the evaluation of the cardiovascular response and allows us to better understand the training concept of CrossFit®. The previous assumption that CrossFit® mainly performed at vigorous training intensities was challenged by the present study. Nevertheless, CrossFit® workouts are known for being performed with high effort [4]. However, when CrossFit® is practiced in 1-h training sessions, the assumption that this high level of effort must be maintained throughout the entire duration of the session is misleading. Rather, our results suggest that the CrossFit® training concept provides for a progressive cardiovascular load increase during 1-h training sessions, with the maximum HR values, as typical for high-intensity training [40], being achieved only during the WOD in the last part (B-part) of the training session. We were able to show for the first time that the training concept of CrossFit® by practicing in 1-h training sessions may enable a combination of aerobic, anaerobic, and resistance training within each training session. On average, only the smallest amount of training time of a 1-h training session, concretely 14.08% ± 8.71% of training times, occurs at intensities ≥ 91% of HR_{max}, followed by training times at intensities of 81%–90%, of 71%–80%, and of 61%–70% of HR_{max}, in order. A surprising result was that the most of time of a 1-h training session the athletes spent was in Zones with ≤ 60% of HR_{max}. Therefore, we concluded that it is reasonable for the assumption of practicing CrossFit® in a 1-h training session based on the training guide utilizes all three energy systems [18].

The US Department of Health and Human Services, in its Physical Activity Guidelines for Americans (PAGA), requires at least 150 to 300 min per week of moderate aerobic activity or at least 75 min per week of vigorous aerobic activity for adults and also muscle-strengthening activity at least 2 days each week, to obtain health benefits [29]. Our results show that with 2–3 1-h CrossFit® training sessions per week, PAGA recommendations for significant health benefits are achieved. Higher exercise intensities, as shown in this study, result in greater health benefits [14]. Therefore, other studies demonstrated that HIFT is also useful to improve health-related fitness in inactive or overweight adults [2, 11]. Furthermore, since our results showed no significant differences in cardiovascular responses between beginner and experienced CrossFit® athletes, we suggest that CrossFit® performed in a 1-h training session may provide health and fitness benefits for any athlete, regardless of experience. Since already proven that HIIT can induce improvements in cardio-metabolic disease risk factors [1, 22, 23], based on our findings, future research might investigate the benefits of performing scaled CrossFit® in 1-h training sessions for various health aspects. To achieve positive physiological adaptations without the risk of overtraining and injury, one major challenge in CrossFit® science is the quantification of internal TL. Characterization of the TL is also necessary to analyze the periodization of training. Our study observed the variation of internal TL of 1-h training sessions of a local affiliated training center within 1 week; however, the observed period is too short to predict any evidence about the periodization of the training. However, despite the different training modalities in part-B, the results show that there are no significant differences in internal TL between the investigated 1-h CrossFit® training sessions. Adequate periodization of the internal TL during the training week is important to assure that an appropriate physiological stimulus is provided while ensuring sufficient time for recovery [30]. Based on our results, future studies may analyze the internal TL over a longer period to make recommendations for the periodization of CrossFit® training in 1-h durations.

Despite the novel findings, the study is not without limitations. The limitation of the present study is the lack of RPE measurement as an indicator of the physiological response or to calculate the internal TL by session RPE [35, 36]. Quantifying the internal TL by Edward's method uses only standardized predefined zones in contrast to other methods that use the HR zones based on individual parameters obtained in laboratory [21]. Another limitation is calculating the HR_{max} using an equation instead of experimental measurements, e.g., the Conconi test [5]. Therefore, further investigations should verify our findings by continuing the examination of 1-h CrossFit® training sessions over a longer period of time using experimental measurements of physiological response. Another limitation is the lack of load quantification as weight on the bar due to CrossFit® involving resistance training.

This study showed for the first time the cardiovascular responses and quantified the internal TL of 1-h CrossFit® training sessions. The results of this study demonstrate that practicing CrossFit® in 1-h training sessions, divided into separate parts, shows significantly different HR values during each part; however, heart rate did not differ in the last part (B-part) across the training sessions, which included the WOD. In addition, when comparing the different levels of CrossFit® experience, no differences in HR values and TL were found between beginners and experienced athletes. Our results suggest that CrossFit® training performed in 1-h training sessions is suitable for both beginner and experienced athletes regardless of their CrossFit® experience and may improve their cardiovascular fitness. In summary, our data provide a major contribution for a better understanding of practical training conditions during 1-h CrossFit® classes commonly offered at affiliated training centers.

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Availability of Data and Materials The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The authors have no relevant financial or non-financial interests to disclose.

Ethics Approval and Consent to Participate The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of University of the Bundeswehr Munich, Germany (06/04/2018).

Consent to Participate All participants sign the consent form and confirm their agreement with the use of their data before participation.

References

1. Batacan RB Jr, Duncan MJ, Dalbo VJ, Tucker PS, Fenning AS. Effects of high-intensity interval training on cardiometabolic health: a systematic review and meta-analysis of intervention studies. Br J Sports Med. 2017;51(6):494–503. https://doi.org/10.1136/bjsports-2015-095841.
2. Brisebois MF, Rigby BR, Nichols DL. Physiological and fitness adaptations after eight weeks of high-intensity functional training in physically inactive adults. Sports (Basel). 2018;6(4):146. https://doi.org/10.3390/sports6040146.
3. Butcher SJ, Judd TB, Benko CR, Horvey KJ, Pshyk AD. Relative intensity of two types of CrossFit exercise: acute circuit and high-intensity interval exercise. J Fitness Res. 2015;4(2):3–15.
4. Claudino JG, Gabbett TJ, Bourgeois F, Souza HS, Miranda RC, Mezêncio B, Soncin R, Filho CAC, Bottaro M, Hernandez AJ, Amadio AC, Serrão JNC. CrossFit overview: systematic review and meta-analysis. Sports Med Open. 2018;4(1):11. https://doi.org/10.1186/s40798-018-0124-5.
5. Conconi F, Grazzi G, Casoni I, Guglielmini C, Borsetto C, Ballarin E, Mazzoni G, Patracchini M, Manfredini F. The Conconi test: methodology after 12 years of application. Int J Sports Med. 1996;17(07):509–19.
6. Cosgrove SJ, Crawford DA, Heinrich KM. Multiple fitness improvements found after 6-months of high intensity functional training. Sports. 2019;7(9):203.
7. CrossFit. About affiliation. 2021. https://www.CrossFit.com/affiliate. Accessed 15 Nov 2021.
8. Drake N, Smeed J, Carper MJ, Crawford DA. Effects of short-term CrossFit™ training: a magnitude-based approach. J Exerc Physiol Online. 2017;20(2):111–33.
9. Edwards S. High performance training and racing. Heart Rate Monitor Book. 1993;12(2):113–23.
10. Falk Neto JH, Tibana RA, de Sousa NMF, Prestes J, Voltarelli FA, Kennedy MD. Session rating of perceived exertion is a superior method to monitor internal training loads of functional fitness training sessions performed at different intensities when compared to training impulse. Front Physiol. 2020;11:919.
11. Feito Y, Heinrich KM, Butcher SJ, Poston WSC. High-intensity functional training (HIFT): definition and research implications for improved fitness. Sports (Basel). 2018;6(3):76. https://doi.org/10.3390/sports6030076.
12. Fernández JF, Solana RS, Moya D, Marin JMS, Ramón MM. Acute physiological responses during CrossFit® workouts. Eur J Human Mov. 2015;35:114–24.
13. Forte LD, Freire YG, Júnior JS, Melo DA, Meireles CL. Physiological responses after two different CrossFit workouts. Biol Sport. 2022;39(2):231–6.
14. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee I-M, Nieman DC, Swain DP, American College of Sports Medicine. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc. 2011;43(7):1334–59. https://doi.org/10.1249/MSS.0b013e318213fefb.
15. Gianzina EA, Kassotaki OA. The benefits and risks of the high-intensity CrossFit training. Sport Sci Health. 2019;15(1):21–33.
16. Glassman G. What is fitness. CrossFit J. 2002;1–11.
17. Glassman G. What is CrossFit? CrossFit J. 2004;1–7.
18. Glassman G. The CrossFit training guide. CrossFit J. 2010;1–115.
19. Gordon J. Scaling CrossFit workouts. CrossFit J. 2015;1–7.
20. Hopkins BS, Li D, Svet M, Kesavabhotla K, Dahdaleh NS. CrossFit and rhabdomyolysis: a case series of 11 patients presenting at a single academic institution. J Sci Med Sport. 2019;22(7):758–62.
21. Houcine N, Ouergui I, Chaabene H. Training load monitoring. Foster city: OMICS group eBooks; 2015.
22. Jelleyman C, Yates T, O'Donovan G, Gray LJ, King JA, Khunti K, Davies MJ. The effects of high-intensity interval training on glucose regulation and insulin resistance: a meta-analysis. Obes Rev. 2015;16(11):942–61. https://doi.org/10.1111/obr.12317.
23. Kessler HS, Sisson SB, Short KR. The potential for high-intensity interval training to reduce cardiometabolic disease risk. Sports Med. 2012;42(6):489–509. https://doi.org/10.2165/11630910-000000000-00000.
24. Klimek C, Ashbeck C, Brook AJ, Durall C. Are injuries more common with CrossFit training than other forms of exercise? J Sport Rehabil. 2018;27(3):295–9. https://doi.org/10.1123/jsr.2016-0040.
25. Kliszczewicz B, Snarr R, Esco M. Metabolic and cardiovascular response to the CrossFit workout "Cindy": a pilot study. J Sport Hum Perf. 2014;2(2):1–9.
26. Mangine GT, Stratton MT, Almeda CG, Roberts MD, Esmat TA, VanDusseldorp TA, Feito Y. Physiological differences between advanced CrossFit athletes, recreational CrossFit participants, and physically-active adults. PLoS ONE. 2020;15(4): e0223548. https://doi.org/10.1371/journal.pone.0223548.
27. Maté-Muñoz JL, Lougedo JH, Barba M, Cañuelo-Márquez AM, Guodemar-Pérez J, García-Fernández P, Lozano-Estevan MC, Alonso-Melero R, Sánchez-Calabuig MA, Ruíz-López M, de Jesús F, Garnacho-Castaño MV. Cardiometabolic and muscular fatigue responses to different CrossFit® workouts. J Sports Sci Med. 2018;17(4):668–79.

28. Meier N, Thaden T, Schmidt A. Delayed increase in blood lactate concentration after a short, intense CrossFit® workout. Arch Clin Med Case Rep. 2021;5:468–78.
29. Piercy KL, Troiano RP, Ballard RM, Carlson SA, Fulton JE, Galuska DA, George SM, Olson RD. The physical activity guidelines for Americans. JAMA. 2018;320(19):2020–8.
30. Rowbottom DG. Periodization of training. Exerc Sport Sci. 2000;499–512.
31. Smith MM, Sommer AJ, Starkoff BE, Devor ST. CrossFit-based high-intensity power training improves maximal aerobic fitness and body composition. J Strength Cond Res. 2013;27(11):3159–72. https://doi.org/10.1519/JSC.0b013e318289e59f.
32. Summitt RJ, Cotton RA, Kays AC, Slaven EJ. Shoulder Injuries in individuals who participate in CrossFit training. Sports Health. 2016;8(6):541–6. https://doi.org/10.1177/1941738116666073.
33. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol. 2001;37(1):153–6. https://doi.org/10.1016/s0735-1097(00)01054-8.
34. Tibana RA, de Almeida LM, Frade de Sousa NM, Nascimento Dda C, Neto IV, de Almeida JA, de Souza VC, Lopes Mde F, Nobrega Ode T, Vieira DC, Navalta JW, Prestes J. Two consecutive days of CrossFit training affects pro and anti-inflammatory cytokines and osteoprotegerin without impairments in muscle power. Front Physiol. 2016;7:260. https://doi.org/10.3389/fphys.2016.00260.
35. Tibana RA, de Sousa NMF, Cunha GV, Prestes J, Fett C, Gabbett TJ, Voltarelli FA. Validity of session rating perceived exertion method for quantifying internal training load during high-intensity functional training. Sports (Basel). 2018;6(3):68. https://doi.org/10.3390/sports6030068.
36. Tibana RA, de Sousa NMF, Prestes J, da Cunha Nascimento D, Ernesto C, Neto JHF, et al. Is perceived exertion a useful indicator of the metabolic and cardiovascular responses to a metabolic conditioning session of functional fitness? Sports. 2019;7(7):161.
37. Tibana RA, De Sousa NMF, Prestes J, Voltarelli FA. Lactate, heart rate and rating of perceived exertion responses to shorter and longer duration CrossFit(®) training sessions. J Funct Morphol Kinesiol. 2018;3(4):60. https://doi.org/10.3390/jfmk3040060.
38. Tibana RA, de Sousa NMF. Are extreme conditioning programmes effective and safe? A narrative review of high-intensity functional training methods research paradigms and findings. BMJ Open Sport Exerc Med. 2018;4(1):e000435. https://doi.org/10.1136/bmjsem-2018-000435.
39. Tibana RA, de Sousa NMF, Prestes J, Feito Y, Ernesto C, Voltarelli FA. Monitoring training load, well-being, heart rate variability, and competitive performance of a functional-fitness female athlete: a case study. Sports. 2019;7(2):35.
40. Timón R, Olcina G, Camacho-Cardeñosa M, Camacho-Cardenosa A, Martinez-Guardado I, Marcos-Serrano M. 48-hour recovery of biochemical parameters and physical performance after two modalities of CrossFit workouts. Biol Sport. 2019;36(3):283.
41. Toledo R, Dias MR, Toledo R, Erotides R, Pinto DS, Reis VM, Novaes JS, Vianna JM, Heinrich KM. Comparison of physiological responses and training load between different CrossFit® workouts with equalized volume in men and women. Life. 2021;11(6):586.
42. Weisenthal BM, Beck CA, Maloney MD, DeHaven KE, Giordano BD. Injury rate and patterns among CrossFit athletes. Orthop J Sports Med. 2014;2(4):2325967114531177. https://doi.org/10.1177/2325967114531177.